Creating 3D Tutorial System for Facial Animation: Visualizing Facial Muscle System Based On Facial Action Coding System

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Dedications

I dedicate this thesis and corresponding project to my mother, Xiaoping Hu, and my father, Jun Li. They have always been there during the difficult times in my life. I would not achieve what I have today without their constantly love and support.

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Abstract

Creating 3D Tutorial System for Facial Animation: Visualizing Facial Muscle System Based On Facial Action Coding System

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Facial expression animation is an essential component of the current digital media industry. It brings a vivid, anthropomorphic and evolutionary reality to a multitude of digital fields, such as 3D computer character animations, video games, and interactive multimedia. FACS, short for Facial Action Coding System, is an emotion model proposed by Paul Ekman and Wallace V. Friesen and proven to be instrumental to animators. Therefore, the author feels it necessary to establish a visualization of the FACS system to facilitate people's understanding of it by visualizing the muscles underneath the face.

This project aims to explain the facial muscular system and its relationships with the six basic human emotions of anger, disgust, fear, joy, sadness and surprise. Through examining the related fields with different approaches, the author will produce an anatomically correct skeletomuscular facial rig to demonstrate each of the Action Units of FACS, as well as how they can be used to produce facial expressions of the six basic human emotions.

1. Introduction

When a newborn baby has not yet learned to speak, he is able to communicate with his mother, and obtain information through observing other people's facial expressions. Scientists have even discovered that animals also apply facial expressions for silent communication.

In the field of digital media, accurate facial expression serves as a significant contributor to a successful 3D character animation. Inanimate objects such as cars and planes can be endowed with the illusion of life in animation by giving them human-like facial features which allow them to emote and thereby establish resonance with the audience.

Before creating faces for 3D characters, modelers must first construct them so that they can later move and deform correctly. This requires a solid understanding of facial anatomy and movement. Likewise riggers, whose job is to create the controls for animating 3D characters and their faces, also need to have a profound understanding of facial anatomy and movement. Generally speaking, understanding the facial muscles as well as their movements in facial expression is important for modeling, rigging and animating.

Due to the complexity and everyone's familiarity of the human face, creating facial animation, which accords with the industrial standards of being both believable and emotionally compelling, is usually regarded as one of the greatest challenges in the field of digital media. Therefore, it is necessary to quickly accelerate young animators up to speed.

The most advanced technology used for geometric deformation is the muscle-based model [30]. In many systems, a profound understanding of the muscles is crucial to build face models and create great facial animations. As seen in [39], the expressive wrinkle effects in 3D facial animation and muscle masks, which are established in the light of facial muscle anatomy, play an important role in the facial movement. In another approach [32] of achieving synchronized speech animation, it is considered indispensable for the writers to review the lip muscle anatomy before constructing the system so as to define the possible lip motion., Moreover, when online tutors [6] are producing their facial animation as an educational tutorial, they usually start by addressing face muscle system and explaining muscles with anatomy images in details. For instance, how each of those muscles interacts with another, which muscles are the driving muscles and which are responding muscles. "It is critical to understand that the system under the surface creates expression [6]". Furthermore, a number of facial simulations, as seen in [16] [37] [5], have utilized Facial Action Coding System (FACS) developed by Ekman and Friesen [12]. In the system, human facial expressions are divided into a variety of Action Units (AU) which defines a specific action of a single muscle or a group of muscles.

2. Definition of Terms

FACS

Facial Action Coding System was proposed by Ekman and Friesen in 1978. The FACS consists of over 60 AUs. Ekman et al. believe that human facial expressions can be broken down into those AUs so that a specific expression can be analyzed.

AU

As defined in FACS by Ekman, Action Units serve to recognize the facial regional movement as part of a basic emotion or other blended human emotions such as Joy and Surprise. The AUs represent, inner brow raise, lip corner puller and so on.

Bone

A bone is a means of deforming 3D objects by moving vertices assigned to it. Bones are grouped together to form a hierarchy called ”skeleton”. The pivot point of a bone is called a ”joint”. Thus, bones are often referred to as joints as well.

Vertex

As a point in 3D space, vertex is the very basic component used in 3D modeling process. Two vertices connected by a straight line make an edge, while three vertices connected to each other by three edges become a triangle.

Mesh

Mesh refers to the collection of vertices, edges and faces that define the shape of a 3D polyhedral object.

Blendshape

Blend shape deformers can change the shape of one object into the shapes of other objects, and deform a surface into the shapes of other surfaces. In character setup, a typical use of a blend shape deformer is to set up poses for facial animation.

Rigging

It refers to the process of setting up deformers and controls for a 3D object in order to animate it.

Render

3D Rendering is the process of producing an image based on three-dimensional data stored within a computer.

Animation

It means the creation of moving pictures in a three-dimensional digital environment. This is done by sequencing consecutive images, or ”frames”. Specifically, it simulates motion by showing each image which is filmed by a virtual ”camera” one by one in a gradual progression of steps, and then output them to video by a rendering engine. The eye can be ”fooled” into perceiving motion when these consecutive images are shown at a rate of 24 frames per second or faster.

ZBrush

ZBrush is a 3D application adopted as a digital sculpting tool to create high-resolution models (up to ten million polygons) for use in movies, games, and animations.

MoCap

MoCap is short for Motion Capture. In filmmaking and video game development, Motion Capture refers to recording actions of human actors, and using that information to animate digital character models in 2D or 3D computer animation.

3. Project Description

In this context, the author proposes to do a project that introduces a facial anatomy rig as an educational tool to learn the Action Units in FACS and its relationship with facial muscles, as well as how those muscles move and interact with each other when different expressions are made. In this project, the anatomically accurate human head skeleton and facial muscles will be made to teach animators about facial muscle anatomy. The ultimate goal of this project will be a series of videos that allow viewers to easily access to the face anatomy and familiarize with how those muscles move when expressing different emotions.

In the muscle system, as proposed by Waters based on FACS [12], two broad types of facial muscles, which are linear muscles and sphincter muscles respectively [38], will be explained and visualized. Specifically, linear muscles are shown in three different types: those that move vertically up to the brow and down to the chin, those that move from the lips upwards and outwards to the cheek bones in an angular direction, and those that move horizontally to the ear and back to the center of the face. Sphincter muscles, also known as circular or elliptical muscles, will be presented in areas of eyes and mouth.

At the beginning of the animation, audience will be introduced to the Action Units in FACS, specifically how different groups of facial muscles move to activate each Action Unit. Then they will be shown with the basic human emotions of anger, disgust, fear, joy, sadness and surprise as described in *Basic Emotions* [11]. In expressing anger, for instance, the muscles in brow (e.g., Corrugator Supercilii) are lowered; muscles in upper lid (e.g., Orbicularis oculi) and mouth (e.g., Orbicularis Oris) are tightened according to FACS.

4. Thesis Statement

The author is studying facial muscles, Facial Action Coding System, and their relationships with facial animations for figuring out how to create an animation with 3D software to visualize the facial muscles, fostering animators' understanding of the facial muscle system and the FACS, promoting the fleeting emotions in facial animation, and helping animators to produce more realistic and emotionally-compelling facial animations.

The research question can be formulated as, how can the author utilize the real facial muscle references, knowledge of Facial Action Coding system and Action Units to create a realistic facial muscle rig that can simulate the six human recognizable facial expressions?

5. Background

5.1 Paul Ekman and Facial Action Coding System

Paul Ekman, Professor Emeritus in Psychology at UCSF, is a researcher and author best known for furthering the understanding of nonverbal behavior encompassing facial expressions and gestures. In addition to his distinguished academic career, Ekman has authored more than 100 published articles and holds several honorary doctoral degrees. He is a pre-eminent psychologist and a co-discoverer of micro expressions with Friesen, Haggard and Isaacs. In 2009, Ekman was named as one of the 100 most influential people in the world by *TIME* Magazine [4].

Based on a system originally developed by Swedish anatomist Carl-Herman Hjortsj[20], Facial Action Coding System (FACS) endeavors to apply taxonomy in human facial movements according to their appearances on the face. Later on, Paul Ekman and Wallace V. Friesen adopted and published FACS in 1978 [13]. Ekman, Friesen, and Joseph C. Hager published a significant update to FACS in 2002 [25]. It is a common standard to systematically categorize the physical expression of emotions, which also has been proven useful to psychologists and animators. Additionally, behavioral scientists, CG animators, and computer scientists are interested in pattern recognition programs, and other technicians and scientists also adopt FACS in their professional work when they need to know the exact movements that the face can perform, and what muscles produce them.

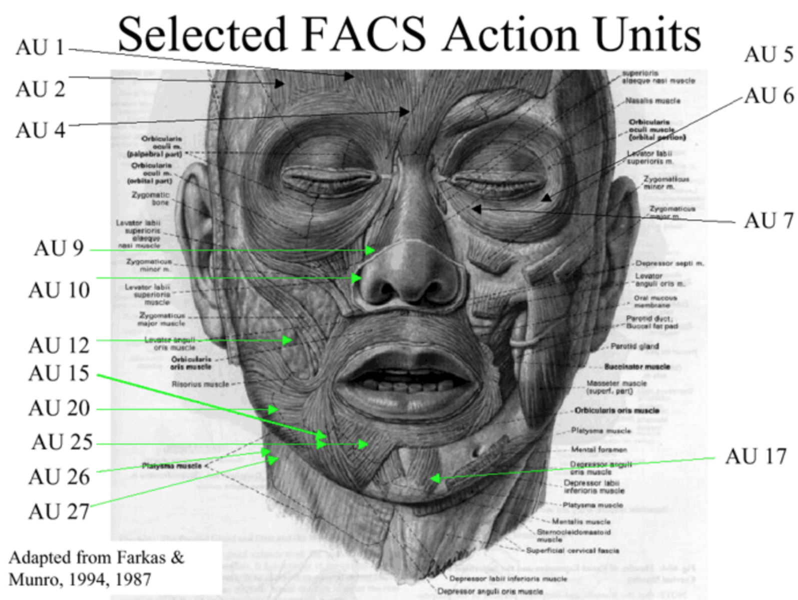

Figure 5.1: FACS and AUs

FACS measurement units are named as Action Units (AUs). Action Units do not correspond with individual facial muscles for two reasons. First, for some expressions, more than one muscle is combined into a single AU because the changes in appearance they produce cannot be distinguished. Second, the changes in expression produced by one muscle are sometimes separated into two or more AUs to represent independent actions performed by different parts of the muscle. A FACS coder "dissects" an observed expression, deconstructing it into the specific AUs that produce the movement. It is found a facial expression consists of various AUs. In other words, various AUs comprise that expression.

5.2 FACS in the Film Industry

Santanu Pal, a Technical Director in the Animation and VFX industry, notes in his article, it is more and more difficult to create exact and believable facial simulations using computer animation. Under this situation, he mentions Facial Action Coding System can be taken as an important tool for simulating facial movement and expression. Later, as a complex combination of various muscular movements on facial muscles, FACS becomes well-known to many studios and VFX technical directors in worldwide.

Thanks to Bay Raitt who took over the animation of Gollum in The Lord of The Ring in 2001, WETA became the first one to use FACS in facial animation [33]. This technology has been adopted in other movies such as Spider Man 3 and Monster House [19] in 2004, King Kong [1] in 2005, The Curious Case of Benjamin Button [17] in 2008, and Avatar in 2009. However, the application of FACS is not only limited to virtual characters in movies. The gaming industry also utilizes the FACS system to produce facial expressions for their characters. Valve, the makers of Half Life 2 can be served as an example.

5.3 Muscle Anatomy and Movement for Topology

Topology refers to the way a 3D model is constructed and how the polygons are placed to form its shape.

Having a proper topology is essential for a 3D character's face, since it enables the face to deform correctly when animated.

Facial movement accounts for a greater proportion of character animation, due to many close-up shots, complex expressions and lip sync animations, all of which require extensive variation in shapes and deformations of the face. Without a proper face topology, facial animation will look unbelievable and unnatural.

5.3.1 Platt and Tron

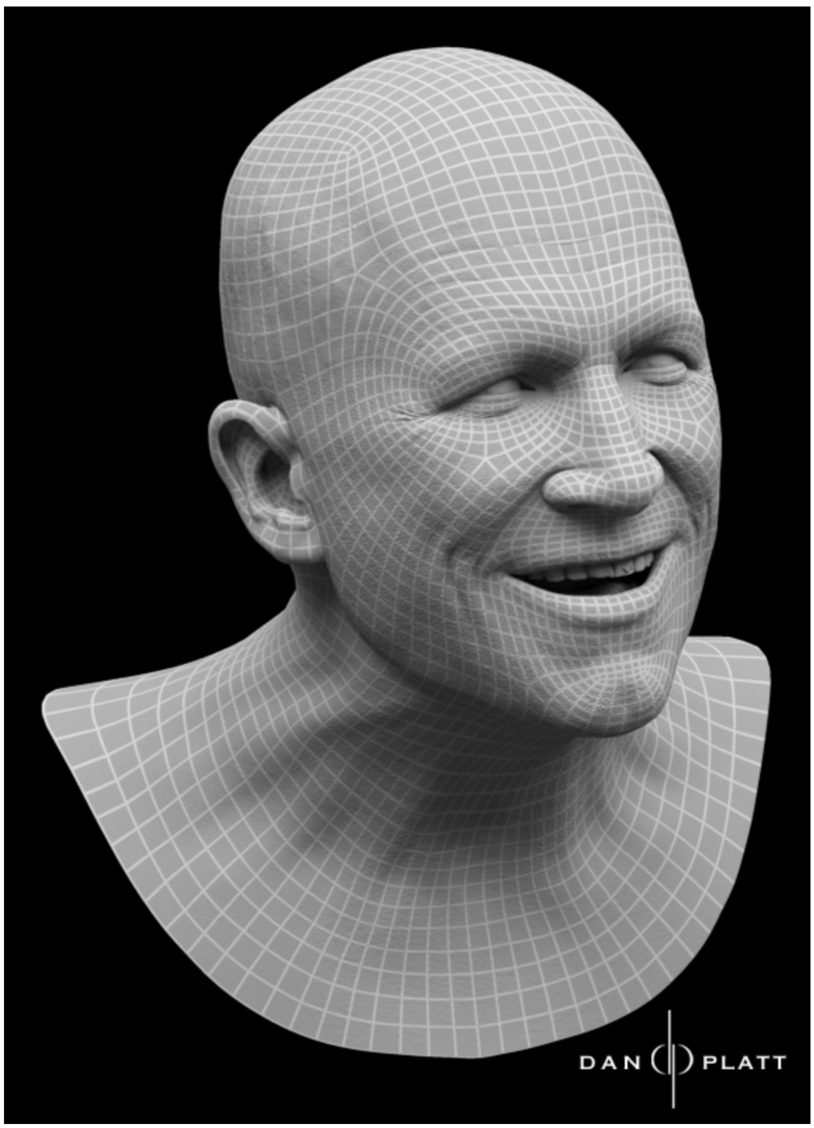

Figure 5.2: Dan Platt's Clu Wireframe

Dan Platt is a photorealistic character modeler wining three-time award and working in the visual effect industry. Platt had lectured and conducted digital modeling seminars in Canada, Sweden, Denmark, Paris, London and the U.S. from 2005 to 2011. Platt taught the Advanced Character Modeling in Maya course at CalArts. While at Disney, he was a modeling mentor, an instructor and modeling representative at a variety of Disney sponsored events [27]. One of the areas that he specializes in is FACS facial modeling.

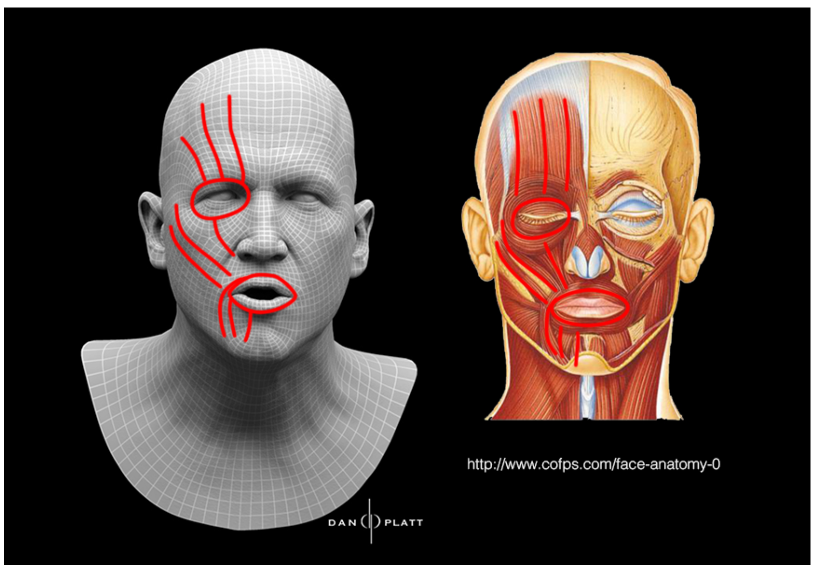

Figure 5.3: Clu in Tron: Legacy, Dan Platt's Organic Model in Wireframe

Above is a picture of Dan Platt's character model of Clu who has over 350 FACS based on blend shapes as "wireframes" in action. As the figure illustrates, in Tron: Legacy, the character model's facial topology is modeled in accordance to facial muscles. Human facial skin is like "a thick sheet of foam rubber lying on a table", and our facial muscles are like "strings" that attach to its underside, said Steven Stahlberg in the book *D'artiste: Character Modeling*. When one or another string is pulled, part of the sheet slides and wrinkles. The foam rubber is like the skin surface and the face model, while the strings are muscles. Modelers decide the topology based on the major wrinkles which are formed by facial muscles. With anatomically-oriented facial topology, it is easier for animators to manipulate these ”strings” to achieve the desired ”wrinkles”.

5.3.2 Osipa, Stop Staring

Facial animation and modeling involves how to lip sync and how to use the eyes, brows, and lids for expression. Good facial animation and modeling, however, need to know much more than that. Good acting and modeling means knowing about the relationships between features on the face [24].

In the step of facial model creation, facial landmarking, as introduced in the book Stop Staring, is a factor that determines the face topology. Landmarking means, ” noticing other cues surrounding what we think we are looking at, that is often where the impressions we get really come from.” [24]

Figure 5.4: Lip Corner Topology from Stop Staring, by Jason Osipa, Wiley Publishing 2010

As indicated by Osipa, the main feature of the face should be landmarked, which is the crease of the mouth area. As the above Figure shows, in a smile, the Orbicularis Oris muscle pulls the lip corner. The tightest point is approximately where the muscles create the smile, and thus the muscles are anchored most firmly to the skin.

In the chapter Constructing a Mouth and Nose, Osipa argues that it is difficult to tell people exactly how to set up the topology of face. However, the principle basically contains two parts: for a part of the face, modelers need to create one edge flow that goes in its moving direction, and then make the perpendicular set of edges capable of defining the deformation for that part of the face [24]. Facial muscles determine the direction where edges move, and thus they can help modelers to figure out the best edge flows.

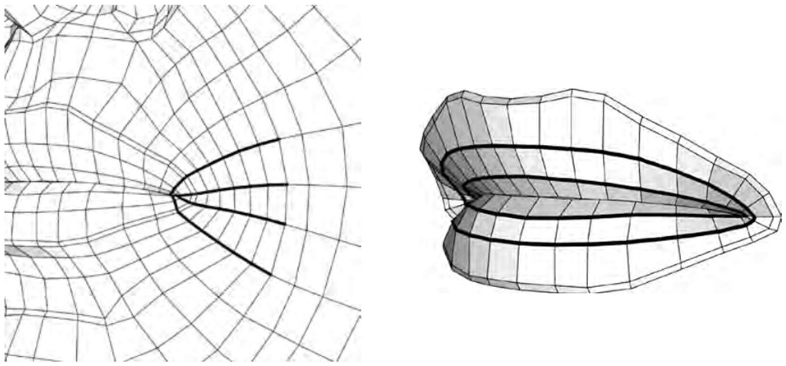

Figure 5.5: Mouth Topology from Stop Staring, by Jason Osipa, Wiley Publishing 2010

In this image, Osipa shows how the muscle influences the topology on the edge loops in corner of the eyes or lip. The muscles in the mouth are very flexible, which also play an important role in many facial expression animations. While planning the face topology, the density of edge loops which depends on the relevant muscle movements is required for animation. In the area that has relatively less deformation, the topology is sparse; whereas in the eyes, mouth, and nose, the topology must be denser.

5.3.3 Escape Studios: Anatomy for 3D Artists

Scott Eaton, the Creative Technical Director at Escape Studios where he founded and now teaches anatomy for digital artists, has consulted for many companies, including Sony, The Mill and Double Negative. In *Anatomy for 3D Artists* [9], Eaton believes that anatomy should inform every aspect of his work. It is also the structural foundation that grounds characters in the physical world and makes them believable, even if they are just cartoons or imaginary creatures. Though artistic vision cannot be taught, Eaton indicates that aspiring artists will find it valuable to receive a firm grounding in the fundamentals of the human form and anatomy.

In Eaton's opinion, the anatomy has been known for thousands of years, but there is little chance to learn it in art school today. In addition, this subject of anatomical fundamentals is decreasing in education, which leads to the fact that few people are qualified to teach this subject. Hence, he claims that this phenomenon makes it difficult for 3D artists to find a decent instructor and thus they must learn anatomy by themselves.

Eaton illustrates this by adopting the example of a modeler who is asked to model a coat hanging in a closet. As a responsible modeler, one might ask the client two major questions: Firstly, what is the kind of coat? Then probably more importantly, what is the shape of the hanger? In this example, the hanger is simulating the skeleton and hanging muscles of the body, while the coat represents the character model.

Understanding these muscular attachments is instrumental to determine the pull direction of the muscle, which also dictates how the edge flow of the model should be laid out.

In *Anatomy Secrets: Scott Eaton* [10], Eaton also indicates that each of his works starts with a sketchbook. ZBrush is one of his tools to bring his sketches to life. He points out that every time in his models, everything is planned in advance, including what the character's poses will look like, and how the anatomy works underneath.

One example the author gives in the article is the sketching of horses. Some of the earliest horses he sketched looked like dogs, while some resembled other creatures but not a horse. This is because he lacked understanding of horse's proportions, mechanics, and anatomy.

”You have to know so much about what is under the surface to articulate, model and animate it", says Scott Eaton.

5.3.4 Brian Tindall, The Art of Moving Points

Face topology designing is based on facial muscles. In the reusable and transferable character facial articulation of Brian Tindall, facial muscle is reflected in his face topology. *The Art of Moving Points* [36] is an excellent guide developed by Brian Tindall for character modelers to design their meshes for production.

Tindall explains how to plan for the face topology in details. Every character uses nearly the same mesh. Brows, eyelids, and lips have the exact same setup from character to character.

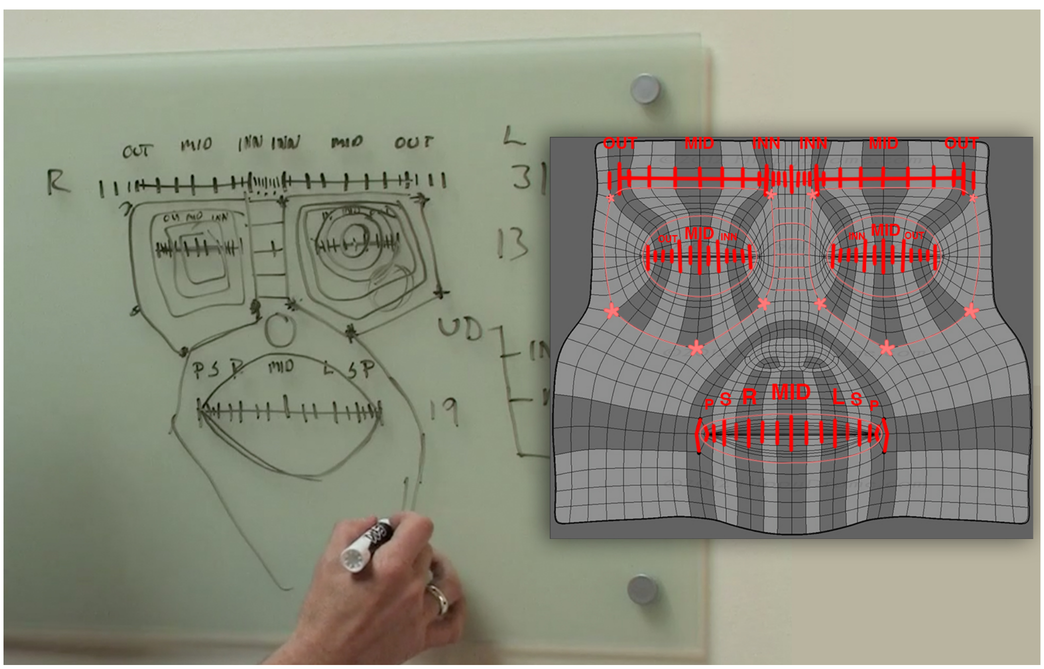

Figure 5.6: Brian Tindall Explains How the Face Mesh is Designed

As seen in Figure 5.6, for instance, the edges in brow is relatively wider and thinner than those in eyes, because Frontalis muscle has less deformation in facial expressions compared to Orbicularis Oculi muscle. The edges in eyes and mouth are denser. Especially, in the corner of eye and mouth, for it usually needs two extra spans on both inside and outside to hold the curves so as to avoid distort. Tindall also introduces Direction Change Point, which refers to a point that shares five polygons in a mesh. As can be seen in the Figure, there are five Direction Change Points around the eye region. One important example is that when the edges in lower eyelid extend to cheek, they turn into two different directions: one edge flow goes in the direction where Zygomaticus Major Muscle pulls lip corner out, and another edge becomes perpendicular to it so as to define the deformation. In the center of brows, the Direction Change Point serves to achieve a furrow crease that flows towards the corner of the eye when the brows depress. By using Direction Change Point, artists can easily modify the edge flow of face in accord with the movement of muscles and figure out the best topology.

From the results, it is obvious that the edge loops in the eye resemble the Orbicularis Oculi muscle, while the edges on side of the mouth pull the lip corner like Risorius muscle. Modelers should carefully plan their facial topology before production so as to grasp the correct movement when animating.

5.4 Muscle anatomy and movement for rigging and animation

5.4.1 Rigging and Anatomy

Joint-based facial rigging is currently one of the most popular approaches in facial animation. It’s where a series of joints are placed and then connected to the model. The joints can be translated, rotated and sometimes scaled to form plenty of facial expressions and poses.

”Understanding anatomy is essential when you are rigging a character. Everything from where you place the joints in the character to how you weight them should all take anatomy into consideration” [18], says Joe Harkins, Creature TD, at Tippett Studio, in Berkeley, CA, who is mainly responsible for character setup and animation for commercials and film.

Harkins argues that typically when the character is modeled, the next step is to set up the joints and figure out the way they move to deform the model. Appropriate joint placement is essential to a rig, for improper joint setup will result in an unnecessary additional workload in skinning and animating. To answer the question of what kind of joints should be used and what direction should the joints move in, a good amount of anatomy reference is needed for riggers.

Antony Ward is a Freelance Digital Artist, Animator and Writer, who has published three technical manuals, Game Character Development in Maya (2004), Game Character Development (2008) and 3D modeling in Silo (2010), and many other tutorials. These tutorials are popular in the animation community and have been translated into many different languages.

Figure 5.7: Kila Facial Rig

In the game character Kila, Ward places 26 joints on the facial area where the muscles move the most. In detail, he utilizes 10 joints to achieve the expressions on the lip; 4 joints to enable the eyelid to blink, squint and look shocked; and 6 joints on the eye brows to express different emotions. Since the nostril area will move as the mouth moves, it would also be necessary to allow a joint on either side of the nose, which also helps to express a sneer. Lastly, Ward notices that cheek pulling and raising are also crucial to facial animations and they need at least 4 joints.

As shown in Figure 5.7, the basic joint setup in Ward's facial system represents the main facial muscle groups to create human basic emotions. For instance, Orbicularis Oris and Zygomaticus Major are two muscles near the mouth that activate lip corner pulling and depressing, which are two key Action Units discussed in Ekman's FACS. In Ward's facial rig, almost half of the joints on the face are located at mouth and cheek; Frontalis and Corrugator Supercilii are responsible for raising and lowering the brow and thus they are also regarded as important Action Units. As a result, 6 joints are placed on the brows to manipulate its motion. As the nose wrinkle only appears in expressing Disgust which is seen less in other facial expressions, riggers usually leave only two joints to control the nostril area.

5.4.2 Pixar Movies: The Incredibles and Brave

In the Pixar film, The Incredibles, a new technology called ”Goo” was developed. It allows the skin to react to the muscles sliding and sticking underneath in a very true fashion.

Previously, it was considered very difficult to create muscles that would flex and ripple like true muscles. In fact, this article also indicates that computer animators have long avoided human-like characters because of their complexity. Tony Fucile, one of the supervising animators for The Incredibles, states in this article: ”Human characters are fairly impossible to animate because we spend our whole lives watching other humans and we know right away when something, even the smallest little thing, isn’t quite right.”

Before the actual production of The Incredibles, copies of the classic medical school book Gray’s Anatomy, were handed out to all the digital sculptors and riggers, hoping to help the team understand how the body moves during each specific action. In this production note, Rick Sayre, the Pixar’s Supervising Technical Director, claims that Skeletons and Muscles are the first keys to realistic articulation and are found deep inside the body. They are where all human motions begin and so it is the same case with the characters of The Incredibles. Therefore, as the team began to create the toughest character, Bob, they developed a completely new and different tool to develop his skeleton and the way his muscles, skin, bones, and fat would attach to it.

5.4.3 Facial Action Coding System for Gollum, Lord Of The Ring

Bay Raitt, the Creature Facial Lead at ”Weta Digital”, was responsible for modeling and building the facial system for the CGI character ”Gollum” in The Lord of the Rings trilogy. Raitt received a Visual Effects Society Award for ’best character animation in a live action motion picture’ for his work on creating Gollum in 2003.

In the article *The Two Towers: Face to Face With Gollum* [33], the production of Gollum’s animation is explained. Gollum was created through a combination of techniques, in which Motion capture was used and it often struggled to capture faces, hands or feet very well. Since MoCap couldn’t be employed for animating Gollum’s face, Bay and his team created a system of sculpted faces based on Facial Action Coding System for the animators. Therefore, the animators would, almost like playing a musical instrument, apply the facial system to display Gollum’s emotional world.

5.4.4 Facial Anatomy and FACS in Motion Capture System

Motion capture of facial expressions is almost exclusively done with optical systems due to the subtlety of the motion involved. In the MoCap system of facial expression, facial data is ”stabilized” by removing the head motion from the data and isolating the local displacement of the facial skin caused by the facial muscles underneath the skin [23].

In facial MoCap system, facial markers are not usually related to an underlying skeletal model as in full-body motion capture. Instead, facial markers are commonly associated with Facial Action Coding System [29]. Through using FACS, animators and MoCap systems can control the Action Units that relate to the activities of facial muscles to create a character's expression.

In the making of Avatar [35], Weta Digital developed some key technologies to simulate realism as accurately as possible before the motion capture process. According to the CG supervisor Simon Clutterbuck, their team created a more accurate skeletal and muscle-simulation system, which has tissue layers, tendon sheets and all the critical parts of a muscle system needs to work.

To achieve realistic facial animation, the team utilized motion capture techniques in which they used a high-definition video camera attached to the face of an actor with tracking markers on their face. Then their in-house software could map out which muscles in the face were firing.

The underlying technology in this Motion Capture system is based on Facial Action Coding System. After capturing the data, they are able to retarget the motion data onto faces that don't match directly by creating a map of muscle firings, and then tweak and adjust the facial animation to get every last nuance to match the desired performance. ”This system allowed us to generate a lot of details in the motion of the faces”, said Andy Jones, the animation director at Weta Digital.

Besides Avatar, FACS was also applied in the Facial Expression Solver in the production of King Kong [26]. According to Santanu Pal, the Facial Expression Solver is a real-time system that captures the performance from the actor in the tracking workstation. The system determines which Action Units in FACS are being activated to create the captured facial expression and automatically map the FACS poses onto a puppet's face. Utilizing the standardized 'language' of the FACS poses allows the system to drive a rig that can make thousands of different facial expressions, including the capture of the very subtle movement to bring the characters into life. Another benefit that the author mentions in his article is that the Facial Expression Solver enables a faithful representation of the original actor's performance compared to other MoCap systems.

Cristobal Curio and others explain another system of retargeting facial motions onto rigs [7]. The authors introduce that this system for realistic facial animation can deconstruct facial motion capture data into semantically meaningful motion channels based on the Facial Action Coding System. The result of their system reached a high level of realism. Using the Facial Action Coding System and the high spatial resolution of 3D scanner, such an animation system allows people to systematically investigate human perception of moving faces, and control over many aspects in the appearance of a dynamic face.

In the system, the Action Units that approximate natural muscle activations provide an intuitive and accurate system for annotating facial motion. As stated by the authors, using FACS as a basis has two additional advantages. Its semantics can help people easily retarget the captured motion onto any face model which uses the same semantic structure. In contrast to approaches that use statistical concepts such as Principle Component Analysis, Action Units can be verbally described. Thus, matching facial expressions can be generated by actors or artists.

6. Methodology

6.1 Research Methodology

One of the author's goals is to simulate realistic facial muscles with 3D software and digital media techniques. Prior to the actual stage of modeling, rigging, and animating, it is necessary to solve some technical issues and research the theories about facial muscles. Firstly, as the analysis and classification of facial muscles are based on Ekman's FACS, the author did some related researches about FACS and its connection to facial anatomy. Secondly, with the help and advice of the author's committee members, the author gained some real photos of facial muscle anatomy and scanned images from anatomy books. These materials and data helped the author to acquire much underlying knowledge, which also saved much time before modeling and rigging. The author will introduce the knowledge gained from these earlier studies.

6.1.1 Overview of Facial Muscles

Posture and gesture can have a decisive effect on the emotion, but the face alone can communicate the full range of human emotion. By just focusing on the face, we can learn many valuable and important things that are no less true because they are also part of a larger context [14].

The facial muscles are subcutaneous (just under the skin) muscles that control facial expression. They generally originate from the surface of the skull bone (rarely the fascia), and insert on the skin of the face. When they contract, the skin moves. These muscles also cause wrinkles at right angles to the muscles action line. The application of these muscles is noted in an extraoral examination, assuring functions of the nerve to these muscles [15].

According to other resourses [21], facial muscles system can be divided into three main groups.

The Orbital Group

The orbital group of facial muscles contains two muscles associated with the eye socket. These muscles control the movements of the eyelids, which are important in protecting the cornea from damage. They are both innervated by the facial nerve.

The Nasal Group

The nasal group of facial muscles is associated with movements of the nose, and the skin around it. There are three muscles in this group, and they are all innervated by the facial nerve. They serve little importance in humans.

The Oral Group

The oral group is the most important group in the facial expressors that are responsible for movements of the mouth and lips. Such movements are required in singing, whistling, especially vocal communication. The oral group of muscles consists of the Orbicularis Oris, Buccinator, and various smaller muscles.

6.1.2 Muscle Tissues

In the research step of this thesis, three types of muscle tissue recognized in vertebrates will be introduced:

Skeletal Muscle or ”voluntary muscle” [8] is anchored by tendons to bone and is used to affect skeletal movement such as locomotion and maintaining posture. Though this postural control is generally maintained as an unconscious reflex, the muscles are responsible for reacting to conscious control like non-postural muscles.

Smooth Muscle or ”involuntary muscle” [34] is found within the walls of organs and structures such as the esophagus, stomach, intestines, bronchi, uterus, urethra, bladder, blood vessels, and the arrector pili in the skin (in which it controls erection of body hair). Unlike skeletal muscle, smooth muscle is not under conscious control.

Cardiac muscle [28], is also an ”involuntary muscle” but is more akin in structure to skeletal muscle, and is found only in the heart.

Through the research of facial muscle anatomy, it is concluded that some of the real facial muscles are not simply placed on top of the bone; instead, some facial muscles are blending with the skull, or with other muscles nearby. Temporalis muscle, for instance, is one of the mastication muscles. The fiber on the edge of Temporalis muscle is blending with skull and they appear in the same layer. Orbicularis Oculi muscle, i.e. the muscle around the eyes, is blending with the Frontalis muscle that located on the forehead and will be activated when the brow is lowering and rising.

6.1.3 The Function of Each Main Facial Muscles

In average, human contains over 40 muscles in the face, The majority of these are controlled by the facial nerve [22], but only parts of which are the most common and significant, because human facial expressions and emotions are not generated from all of the relevant facial muscles. According to Ekmans Action Units, some facial expressions contain only two or three sets of the muscles. For instance, the expression of happiness is generated by two Action Units, which are Action Unit 6 and 12 [13]. Action Unit 6 represents the Cheek Raiser and Action Unit 12 contains Lip Corner Puller. With these two AUs, a believable facial expression of happiness can be simulated. Therefore, in the real production, due to time and resource constraints, the author will only focus on those main facial muscles that have been mentioned by FACS, which have played a decisive role in this step. Instead of scrutinizing every muscle on the face and looking into different research papers and analysis, now only 27 AUs, i.e. 20 main facial muscles, are needed according to FACS,. In the FACS, Ekman carefully classified Action Units into three sections Which are in the upper face, in the lower face, and in the neck respectively.

List of the Main Muscles Introduced in Action Units from FACS [14].

Frontalis:

Pars Medialis: it is the middle part of the frontalis, and the forehead muscle. When it is activated, it will cause the inner tip of the eyebrow to raise. Wrinkles become visible in the middle of the forehead.

Pars Lateralis: as a part of the forehead muscle frontalis, it can cause the outer side of the eyebrows to raise, in which the activated wrinkles are visible on the side of the forehead.

Corrugator Supercilii: it originates on nasal bridge; attaches to skin under middle of eyebrow, and lowers inner end of eyebrow. It forms vertical wrinkles between the eyebrows and horizontal wrinkles above the nose. It will be activated when people frown, and thus it is also known as the frowning muscle.

Depressor Supercilii: it is a muscle located above the eye and on the side of the nose. Together with the corrugator muscle, it lowers the eyebrow when activated so as to create a frown.

Levator Palpebrae Superioris: the muscle that raises the upper eyelid.

Orbicularis Oculi:

Orbitalis Part: the orbital portion is thicker and of a reddish color; its fibers form a complete ellipse without interruption at the lateral palpebral commissure; and the upper fibers of this portion blend with the Frontalis and Corrugator.

Palpebralis Part: the inner part of the orbicularis oculi is a muscle that controls the eyelids. The upper part raises the upper eyelid when activated so as to create a stare or gazing look. When the lower part is activated, it makes a squinting expression and involuntarily relaxes the upper lid.

Levator Labii Superioris Alaquae Nasi: the ”lifter of both the upper lip and of the wing of the nose”. It has the longest name of any muscle in an animal. The muscle is attached to the upper frontal process of the maxilla and inserted into the skin of the lateral part of the nostril and upper lip.

Levator Labii Superioris: it is a muscle that pulls up the upper lip. It runs on top of the levator anguli oris and under the orbicularis oculi. When activated, this muscle creates an umbrella like fold around the nose under the cheeks. It gives a clear hateful or disliking expression to the face. It’s one of three muscles that pull up the upper lip. The others two are the levator labii superioris alaeque nasi and the zygomaticus minor.

Zygomaticus Minor: the Zygomaticus minor is a muscle that is attached to the outer part of the upper lip, drawing it upward and outward when activated.

Zygomaticus Major: or simply the Zygomatic, is a muscle that is attached to the corners of the mouth. It is the only mouth altering muscle involved when a person is laughing genuinely.

Levator Anguli Oris: The Levator Anguli Oris or Caninus is a muscle that pulls the corner of the mouth straight upward. It's often activated on one side only.

Buccinator: the Buccinator is a muscle the runs from the corners of the mouth very deep under the skin behind all other muscles. When activated, it pulls the lips tightly over the teeth. It compresses the cheeks and causes a dimple beside the corner of the mouth.

Depressor Anguli Oris: the Depressor Anguli Oris is a muscle that is attached to the lower lip at the corner of the mouth. When activated, it pulls the corners of the mouth down to cause a typical sad look.

Depressor Labii Inferioris: the depressor labii inferioris is attached to lower lip which is the orbicularis oris. When activated, it pulls the lower lips down and outwards.

Mentalis: the Mentalis is a muscle that runs at the middle of the chin. When activated, the chin is pulled upwards (risen). The mouth gets a round shape with the corners downwards.

Incisivii Labii Superioris / inferioris: it is a part of the orbicularis oris (the muscle surrounding the mouth). When activated, the lips are puckered.

Risorius: the muscle in the face that runs from the corner of the mouth to the side of the cheek and into the Platysma. When activated, the risorius stretches the mouth.

Platysma: the Platysma is a major muscle that covers most of the chin and the foreside of the neck. When activated, the mouth corners are pulled to the side, the lower lip is pulled down somewhat and the stress is visible in the whole neck.

Orbicularis Oris: The Orbicularis Oris is a very flexible muscle that surrounds the whole mouth and is the tissue of the lips. The different strands of this muscle allow the mouth to be formed into a lot of shapes. The orbicularis oris is associated with the tongue whose main muscle is involved in talking.

Masseter: Masseter is a muscle that runs from below the jaw to the skull behind the cheekbone. Its primary purpose is to chew the food. When you are tensed, it can be seen clearly at the back corner of the chin while the rest of the face remains almost unchanged.

Temporalis: it is one of the muscles of mastication. It is a broad and fan-shaped muscle on each side of the head that fills the temporal fossa, which is superior to the Zygomatic arch for it covers much of the temporal bone.

6.1.4 Muscles that are ignored in other Learning Materials and Tools

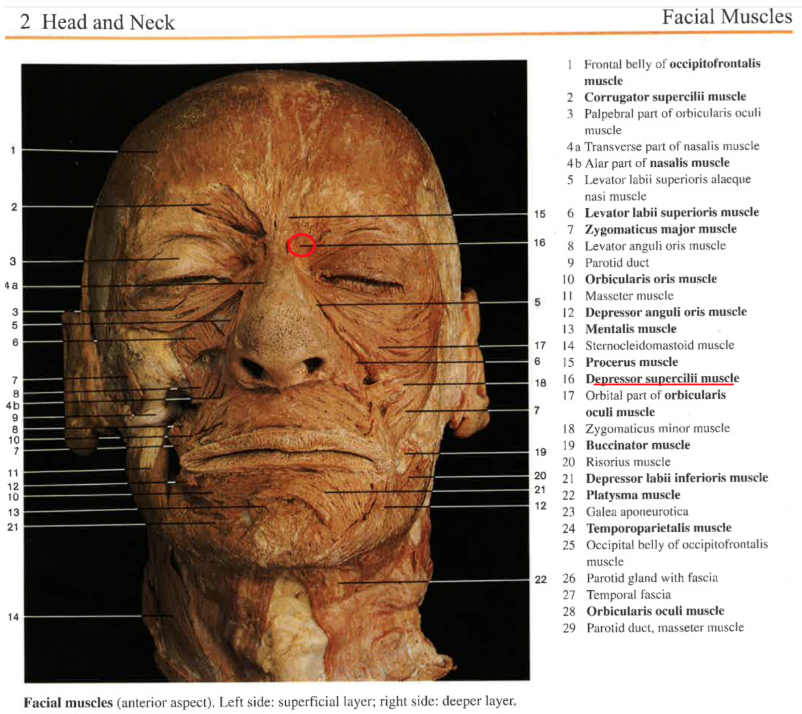

Figure 6.1: Depressor Supercilii Muscle

In the research, the author finds that in some learning websites [2] [3], some muscles, which are significant in the creation of facial expression to a certain degree, are ignored. However, those neglected muscles appear in Ekman's FACS, and are included in the Action Unit, such as Depressor Supercilii and Levator Anguli Oris. Depressor Supercilii muscle exists in Action Unit 4, i.e. Brow Lower, which contains two facial muscles of Corrugator supercilii and Depressor supercilii. In this project, all the muscles in upper and lower face that have been mentioned in FACS will be incorporated, and modeled and rigged in accordance with their anatomical locations, shapes and functions.

6.1.5 Facial Muscles and Six Basic Emotions

This part is based on the part three of the book *The Artists Complete Guide To Facial Expression* [14]:

When Sadness is activated, the signature wrinkles of full Oricularis Oculi contract, smile shapes folded, and star wrinkles between the eye and lowered brow, dominating the upper face. A single crow foot wrinkle is the precursor of more to come. Dimple and bulging are characteristic of contracted corrugator. Puffed cheeks and nasolabial folds are caused by sneering muscle; whereas bracket folds at mouth corner by Risorius and Platysma.

The expression of anger revolves around the eyes. The wider they open, the angrier they look. The muscles involved in anger include: Corrugator, and Orbicularis Oculi (eyelid portion). Corrugator contraction pulls a horizontal fold across the upper lid. The straightness of the lower lid adds a harsh and staring effect to the eye. Its shape is caused by the contraction of the eyelid portion of the Orbicularis Oculi.

The expression of Joy triggers a weak contraction of Orbicularis Oculi. Then the lower lid bulges, shortens, and rises up on the eye, covering part of the iris; and cheek bunches up below eye with smile-shaped wrinkle between cheek and lid. The jaw drops in the laugh, stretches the skin. The chin moves down and back, pushing up folds between chin and neck. The laughing lips, particularly the upper one, are more thinned and stretched.

When fear is on the face, the mouth drops open. The lip stretcher acts when we are afraid. A completely relaxed upper lip and a horizontally-stretched lower lip will show up. In terms of the eyes, they open as wide as possible. In fear, horizontal wrinkles often appear across full forehead; they appear only in the center to show sorrow. The eyebrow is more straight than arched. Inner eyebrow end is usually kinked. Brows are also closer together when bumps appear between them.

The signature looks of disgust are the brow lowered, eyes squinted, curved fold under eye, inner star-wrinkles, creases alongside nose and upper lip squashed, which pulled into face. The muscles involved are Corrugator, Orbicularis Oculi, Levator Labii Superioris and Mentalis. When disgust is activated, the upward pull of the sneering muscle brings the upper lip closer to the nose and fills out the lip corners.

When a person is surprised, two variations of the surprised mouth are shown. Mouth dropped open or O shaped with pursed lips. The muscles involved in surprise include Frontalis, Levator Palpebrae, and Orbicularis Oris.

6.2 Development Methodology

6.2.1 An Attempt at Real Skull Scan

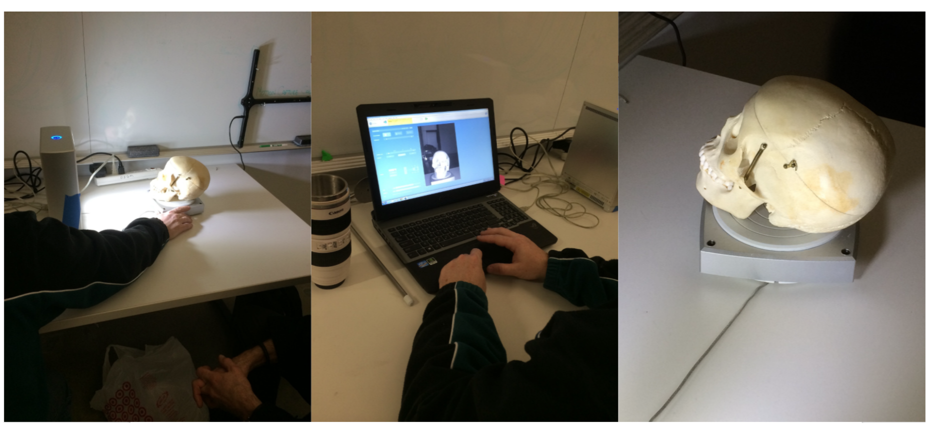

Figure 6.2: Scanning a Real Skull

One of the author's preliminary development methodologies is 3D scanning of the real skull. The faculty members of Digital Media program in Drexel offered great help to the author in this step. A real skull was scanned with 3D scanner in the motion capture room and Next Engine software is adopted to edit the scanned data. In practice, it had been scanned for 16 times around the real model, captured the 3D data with the reflection of the laser ray and then transformed into 3D digital model. The reason why the author wanted to use the real skull is that he also aims to create realistic facial muscle. Modeling a skull in Maya with real anatomy photo as reference is a time-consuming work, and it is not as relevant to this project as sculpting realistic muscles. Hence, the author decided to do scanning. The results of the scan contain 4 different pieces, because the top, bottom and the inside part of the skull cannot be captured for each scan. Therefore, after the scan session, he has to fuse the primary models with the three extra scans. By aligning those four pieces together, they can be fused into one complete skull. To align each two pieces, the author has to put at least three pins on different places on both models to let computer identify locations on the objects.

Unfortunately, it is very difficult to find the locations that are accurate enough to align two pieces, then he tried to adjust it in ZBrush and Maya, but the result was not quite satisfying for his rig.

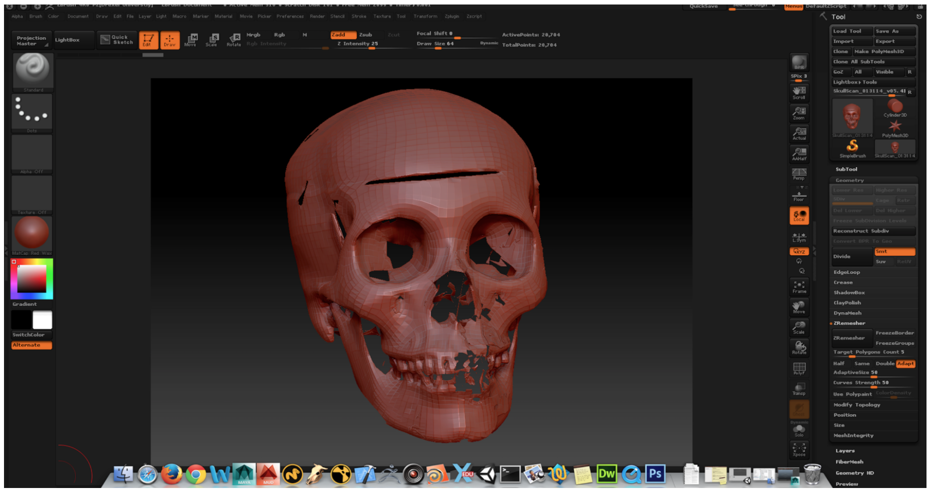

Figure 6.3: Fused Skull in Zbrush

As seen in Figure 6.3, there is a gap on the forehead. This is because the two different models of scanning and fusing are separated, but it is not completely accurate. Thus the author has to give up the 3d scan way as well. Later, the author has to apply the model that his advisor Professor Dave Mauriello sent to him. He got the skull from other resources [31].

6.2.2 Maya Modeling

One of the goals of this project is to create realistic facial muscles with believable details and textures. One challenge lies in the fact that it is difficult to find the ideal reference images of real cadaver's facial muscle on the Internet. On one hand, the high-resolution photos are costly and hard to find, and on the other hand, it takes time to make the decision of what the right categories of anatomy photos would fit in this project. There are a lot of anatomy photo references ranged from different anatomy systems in face, for instance, anatomy photos with respiratory system and nervous system, etc. However, what the author needs would ideally be a clear and understandable reference of only facial muscles, which is very difficult to find especially for a student who is not majored in medical and anatomy. In this regard, one committee member who teaches anatomy offered great help to the author. From his professional textbooks, the author got some scanned photos of facial muscles from real cadaver and the corresponding names of each muscle. These pictures are free and very informative. The photos clearly illustrate the facial muscle tissue structure and the look of the fibers on the muscles.

However, the realism of these photos also brings more challenge to Maya modeling workflow. Previously, the author used Autodesk Maya to build 3D models, but there should be a lot of details on the real muscle model, such as a high number of faces and polygons as well as a detailed structure on the model. In Maya modeling, models are created through moving each single vertex or a small area of vertices, and thus it is relatively time consuming to actually model each of the real muscles in Maya. Consequently, the author looked into ZBrush to further modify the rough version of models, and the ZBrush part will be discussed further in the sculpting section.

At the beginning of the modeling stage, the author applied Maya software to complete the rough version of facial muscles, and then did a preliminary rigging test. After testing, the author was faced with two different options for completing this project: First, the author could export the normal map and displacement map after sculpting the high resolution muscles in ZBrush, and then apply the maps onto the low poly Maya models. Another approach is to import the sculpted high poly model directly into Maya without using both normal map and displacement map, and then texture the high poly models in Maya. The drawback of animating the muscles in high poly models is that the system will be slow and delayed because the high number of faces in the models take up a large amount of computer memory, which not only wastes time and system resources, and also decreases the efficiency of animating facial expressions. In this regard, using the first solution of animating with low poly models can solve this problem. However, the second solution can effectively avoid potential unknown problems when applying normal map and a displacement map to models. After that, each of the approaches was carefully tested. For the first approach of applying normal map and displacement map, the normal map worked fine with the low poly models, but the displacement map did not produce the desired results.

Therefore, the author tried to adjust the different parameters of the displacement map to achieve the desired effect, but the result was still not what it supposed to be. Finally, the author decided to adopt the second approach which directly imports the high poly model into Maya after finishing the sculpting part in ZBrush, and then sets off for the rigging.

6.2.3 Rigging Method Research

As a student majored in digital media, the author has some experience about character rigging, but this project is still challenging, for the prior facial rigging experience of the author was limited and not adequate enough to fulfill the requirements of realism and believability in this project. Previously the author only used several joints to translate and rotate the eyeball and head as well as basic blendshapes to make simple facial animations such as blinking and mouth corner raise. For the rigging process of this project, the technical skills of the author needed to be perfected to make an accurate and real facial anatomy based on rig.

After months of research, the author reviewed and studied three popular methods of facial rigging, which have been proven useful and efficient to many animators. One of these methods was a process of completely controlling a certain region on the face by joints; another way is to control the facial muscle through different shape of curves. Lastly, the third approach is utilizing blendshapes to directly define the ultimate look of a particular region of the face, such as brow lower and rise. Each of these three approaches has their own benefits.

The strength of using a joint-based approach is that the rigger can set up as many controllers on joints as they need for animators, so as to control each muscle more precisely. But to make use of such system has its issues. For instance, the use of merely joints to control muscles would potentially increase the workload of weight painting. Weight painting defines how much the joints influence the mesh when they move, which can be done through either editing each individual vertex in the Component Editor or applying Paint Skin Weights Tool to visually paint the influences on a group of vertices. In case of a high poly model which has a huge number of vertices, weight painting becomes an even more formidable task.

Besides the use of joints, controlling the mesh with a curve can effectively create a smooth deformation on the face. Through the control on a specific vertex on the curve, the other vertices nearby will move along with the vertex being controlled on a smooth motion curve, thus creating a smooth deformation in a certain facial area. However, this approach has problems of its own. For example, it may cause a certain amount of uncontrollability on such area, and therefore makes it difficult for animators to create the ideal micro facial expression animation.

Blendshape-based rigging is widely used and applied in a lot of 3D software such as

Maya and 3D Max. It can intuitively exhibit many results in few tweaks. However, compared with a joint-based rig, a blendshape-based rig has some drawbacks. The principle of this approach is creating the key poses and animating from pose to pose.

Due to the nature of blendshape deformation, it is not very suitable for some facial animations such as eyelid blinking, for the interpolation between poses is linear, but the motion requires more of an arc.

6.2.4 Muscle Rigging

After analyzing the various strengths and drawbacks of the three methods, in the rigging process of the project, the author borrowed from these three methods and gave them a certain blend by using the best aspects of each. Especially in the case of this realistic muscle rig, the author hoped that by using this system which blended three methods could save time in the rig tweaking and animating stage, as well as production of realistic muscle movement.

Take the eye rigging as an example. The muscle that causes eyebrow rise should also drive Orbicularis Oculi muscle, which is the muscle around the eye, slightly upward. This kind of micro movement happens when human express corresponding emotions [14]. But in the rigging process, when the author first tried to control these two groups of muscles, he used only two sets of joints with different weights to influence the movement of the eyebrows and the micro movement of the eye socket muscle, but the result was not ideal. After several tests, the author decided to use a combination of curve and joints so that a number of joints can be controlled by the vertices on the curve easily. This rigging method is largely used in this project, such as the muscle in the corner of the mouth which drives the muscles around the mouth and the Zygomaticus Minor and the Major. The principle of this method is to use locators to point constrain each joint on the curve, and then make use of the smooth path of curve to achieve a relatively smooth movement of joints. In this way, each time when a single joint is moving, it will be followed by a number of joints around that single joint in the center. One example that can clearly demonstrate this approach is the mouth corner raise. When the animator is animating this expression, it is unnecessary to tweak every joint near the corner. Instead, he only needs to lift the joint in the corner, other joints next to it will automatically move to a certain position according to the motion path of the curve, which is also the real mouth motion produced by the muscles.

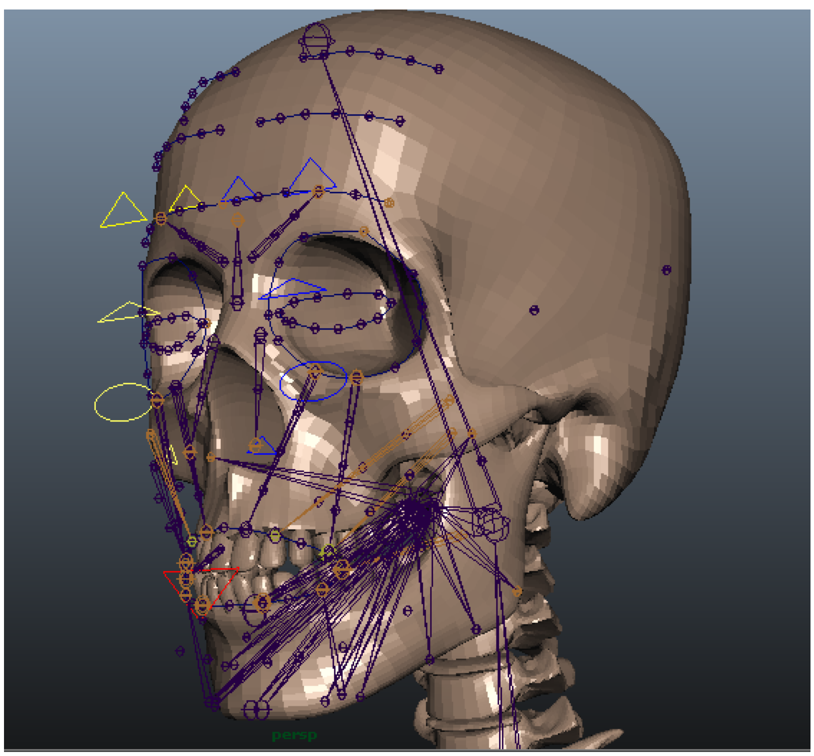

Figure 6.4: Joints on the Face

The author also explored additional methods. For example, the author tried to use clusters to further control each vertex on the curve, thus making it more convenient for the animators to animate different complex facial expressions. Finally, the author decided to combine blendshapes with the curve, apply blendshapes on the curve, and then create expression by the joints on each curve. This approach is effective in creating different facial expressions, and avoids the process of directly shaping the high poly model blendshapes. Additionally, this method makes the entire system much more controllable because if the animator feels dissatisfied with a particular expression, instead of remodeling the blendshapes for the muscles, he can directly adjust the vertices on the curve to create a more ideal facial expression.

6.2.5 Realistic Muscle Sculpting

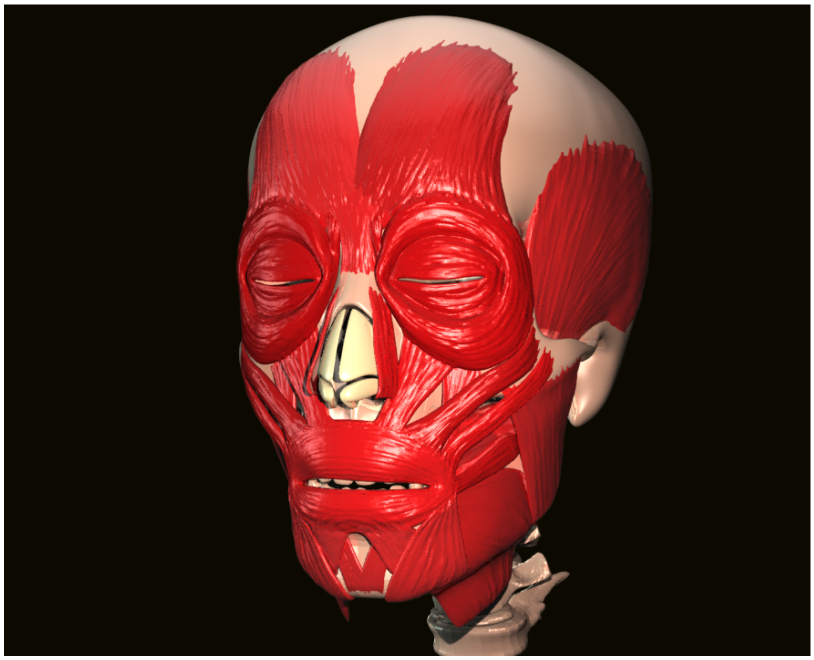

Figure 6.5: Facial Muscles Sculpted in ZBrush

In the sculpting process, the most attention should be paid to three groups of muscles: Temporalis, Orbicularis Oculi and Orbicularis Oris. According to the real facial muscle anatomy photo, the edge of the Temporalis muscle should be blended with the skull; the upper edge of Orbicularis Oculi muscle needs to be blended with the Frontalis muscle which functions in brow raise expression; the corner of Orbicularis Oris muscle should also be blended with Zygomaticus Major, Risorius, and Depressor Anguli Oris muscles. Other muscles like Platysma and Masseter still need to be sculpted, particularly the part in contact with the skull.

7. Result

The final product shows the six human recognizable facial expressions, which are also said to be six universal expressions by Paul Ekman. In animation, the audience will first see the beginning part of the movie, which introduces all the AUs that are used in expressing six expressions. Accompanied with text, the audience can get a thorough understanding of how the muscles move when each AU is activated. Then they will see six basic emotions, as well as the corresponding formulation of AUs. For example, when audience see Happiness, an explanation of the AUs and relevant muscles that create Happiness will be shown up.

The product offers help to both riggers and animators. When rigging a human face, the muscle animation provides a clear reference for the establishment of bones and motion path of each muscle. As for animators, by understanding facial muscles and their internal relations to human emotions, this product can be used as a reference for the production of facial expressions.

8. Conclusion and Future Work

This project is an animation that tells the audience about realistic human facial muscles and Paul Ekman and Friesens famous facial expression recognition method of FACS. In this thesis, an approach to animate facial muscles and visualize the FACS has been put into practice.

In the research and the production step, some information and materials have been analyzed and collected, including some information about the FACS and facial expressions animation. Moreover, facial muscle anatomy photos and several approaches that can be adopted in facial muscle rigging. The information is instrumental in the related future works for other researchers who are interested in deeper study and production.

Before the final results were reached, additional tests were also carried out. Although some of the tests failed, this system can still get a clear and accurate real human facial system and facial muscle movement when expressing the six facial expressions. For future researchers, the failed attempts and methods also provide cases to be studied so as to avoid making these mistakes again.

As far as the future work is concerned, although the approach is feasible in this project, it is not the exclusive and most ideal solution. First, the skull used in this system is not entirely realistic, and it is asymmetrical in some parts, which leaves more or less difficulties to the muscle modeling stage. Moreover, due to the limitations of time and resources, the models of muscles are not accurate enough. This system only covers the main facial muscles that have been mentioned in FACS; however, part of the facial muscles have been altered and even omitted in the production due to various restrictions. For example, Platysma Muscle in this product has the only part in the lower face. In reality, Platysma Muscle extends from the mouth to the chin, and all the way to the chest. Muscles that involved in facial expression creation are far more than the 20 main muscles. There are more muscles on the neck, head, and other minor facial muscles that contribute to facial expression. The limitations of this project will be studied and improved in future research and development to produce a more robust facial muscle system, so as to visualize facial anatomy system more realistically through 3D animation.

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